PROGRESS REPORT

Interferometric Modulator

BY

JOSEPH FORD

Work done under contract with

OFFICE OF NAVAL RESEARCH

N-onr 248 (01)

LABORATORY OF ASTROPHYSICS AND PHYSICAL METEOROLOGY

THE JOHNS HOPKINS UNIVERSITY

BALTIMORE 18, MARYLAND

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FOREWORD

The subsequent report by Joseph Ford shows the progress we have made in development of a far infrared spectrometer.

Although the signal-to-noise was too low for us to virtually reduce to practice the idea of interferometric modulation, which we wished to do by algebra before doing the same thing automatically and mechanically (and expensively); the results are encouraging. It is apparent that the apparatus would work successfully, automatically and mechanically, with the signal-to-noise available, although it was too poor for virtual algebraic manipulations.

John Strong

I. GENERAL DISCUSSION

The use of filters in the energy limited far infrared (300 microns and beyond) to eliminate a grating's overlapping orders can be particularly undesirable. Lenses are equally undesirable from the standpoint of adjustment and absorption. Thus, Professor Strong suggested to Dr. T. K. McCubbin and the author that an all mirror, grating spectroscope utilizing an additional lamellar grating with mechanically variable groove depth might eliminate undesirable features in far infrared spectroscopy.

A first grating (echelette) with collimator, telescope and slits can be made to deliver only wavelengths λ_1, $\lambda_2 = \lambda_1/2$, $\lambda_3 = \lambda_1/3$, to a second lamellar grating. If the groove depth of the lamellar grating is then varied in a periodic fashion at a given frequency, in the zero-order it can be made to impress an intensity variation of the same frequency on λ_1, twice that frequency on λ_2, three times that frequency on λ_3, etc. Thus the lamellar grating, in its zero order, becomes an interferometric modulator [it "labels" the desirable wavelengths (λ_1) differently than the ignorable ones (λ_2, λ_3 -- etc.)]. The electronic system attached to the signal detector is easily made frequency sensitive; hence, overlapping orders are eliminated. Substitution of mirrors for lenses offers no major problem and will not be considered further in this paper.

The following report describes the progress made by Dr. McCubbin and myself during the past summer in investigating the feasibility of such a system.

II. EQUIPMENT

In order to determine the efficiency of the lamellar grating in terms of the visibility of its fringes, the grating shown in Figure 1 was designed by Dr. McCubbin. It was constructed so that the central piston, at first, could be driven by a micrometer mounted on the back of the outside cylinder. This preliminary driving mechanism thus also served as an indicator of groove depth. This grating was tested with the spectrometer described by McCubbin and Sinton[1] -- a twelve-inch instrument using a Golay cell Detector whose output was displayed on a Leeds and Northrup recorder.

The grating was originally designed to be tested using a lens just in front of the grating face for purposes of autocollimation. This plan proved impractical and the set-up shown in Figure 2 was finally adopted. The lamellar grating was used in slightly divergent light.

III. PROCEDURE AND RESULTS

With the set-up as shown in Figure 2, it was desired to observe the visibility of fringes of the lamellar grating in the region around 300 microns. The echelette grating spectroscope always "locked" at the zero-order of the lamellar grating. Hence, interference is displayed on the recorder in either of two ways: 1) the spectrometer grating is held fixed while the groove depth of the lamellar grating is varied; or 2) the lamellar groove depth is held fixed while the echelette spectrometer grating moves λ_1, etc. through the spectrum. The latter method is the one reported here.

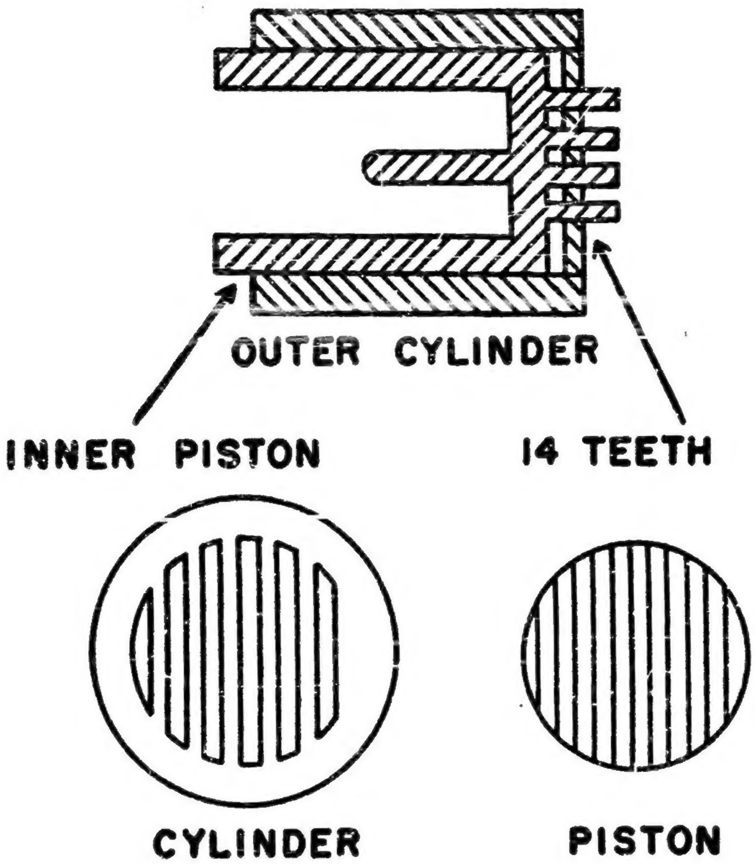


Figure 1.

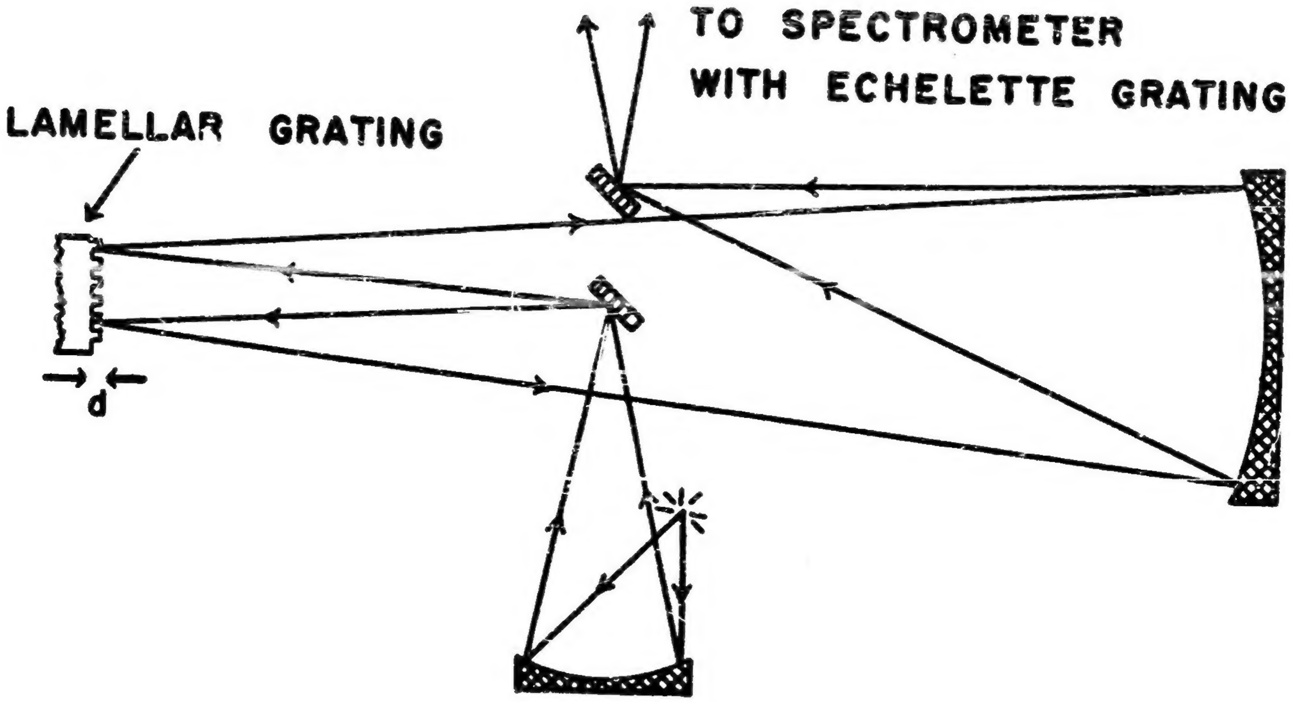

TO SPECTROMETER
WITH ECHELETTE GRATING
LAMELLAR GRATING
d

Figure 2.

The signal-to-noise ratio was poor because of absorption in the rather long air path (four meters); and because of the lack of a sufficiently powerful source of radiations. The Hanovia Mercury Arc which had previously proven superior to other known sources in this region had failed and its replacement has not yet arrived.

The interference was finally studied, as follows: The water vapor spectrum as taken with the spectroscope used in this experiment has consistently shown two anomolous lines[2]-- one at 21 cm^{-1} and the other at 44 cm^{-1}--neither of which are in the calculated spectrum of water. Sinton[3] attributes the one at 21 cm^{-1} to Ozone. The other at 44 cm^{-1} could possibly be the second order (grating) of a strongly absorbing cluster of lines at 88 cm^{-1}. The set-up of Figure 2 was used to investigate the 44 cm^{-1} line. Here we have just the thing the interference modulator is designed to handle.

The depth of the lamellar grating grooves is set (by dead reckoning) to cause destructive interference at 92 cm^{-1} and then a short segment of the spectrum around 44 cm^{-1} is taken with the spectrometer. The depth of the grooves is then changed to destructively interfere (first order interference) at 90 cm^{-1} and the same short segment of spectrum again taken. The procedure is repeated varying the wave number of destructive interference a step at the time down through 84 cm^{-1}. Here we assume that the $\lambda/4$ separation for 90 cm^{-1} will attenuate the 44 cm^{-1} radiation only very slightly. Thus, if the spectrometer grating is casting second-order radiation into the region around 44 cm^{-1}, then the spectra as taken above should show a

"new line" whose position depends on the depth of the lamellar grooves. If this new line did not appear, then clearly no second order radiation appears in the region around 44 cm^{-1}; and hence, the regular 44 cm^{-1} line is not due to water vapor absorption. The preceding discussion presents the idea involved, but that the situation is somewhat more complex will appear in what follows:

The formula for the intensity (zero-order) of the signal leaving the lamellar grating is

$$I = I_{o,\bar{\nu}} \cos^2 2\pi e \bar{\nu}, \tag{1}$$

where e is the groove depth, $\bar{\nu}$ is the wave number, $I_{o,\bar{\nu}}$ is the maximum intensity for $\bar{\nu}$. Thus for a fixed value of e, there will be a group of $\bar{\nu}$ which make I zero, being given by the equation

$$2\pi e\bar{\nu} = (m + 1/2)\frac{\pi}{2}.$$

In particular, for e=188 microns, destructive interference occurs at 40 and 94.5 wave numbers--the other wave numbers for which cancellation occurs lie too far out of the 44 wave number region to be of interest. In the spectrum around 44 cm^{-1} then, the 40 cm^{-1} interference will be in the first order*. The 94.5 cm^{-1} interference will appear as second order at 47 cm^{-1}. Moreover, while the second order of 94.5 cm^{-1} at 47 cm^{-1} is being totally cancelled, the first order 47 cm^{-1} radiation is itself being reduced to one-half its full intensity. This latter follows immediately from equation (1) which shows that whenever $\bar{\nu}$ is suffering total cancellation, $\bar{\nu}/2$ is one-half its maximum value. On the other hand when $\bar{\nu}/2$ is undergoing full cancellation, $\bar{\nu}$ is at full

*Here first and second order refer to orders of the spectrometer grating spectra; as mentioned before only the zero-order of the lamellar grating spectrum is used (although we have first- and second-order interference).

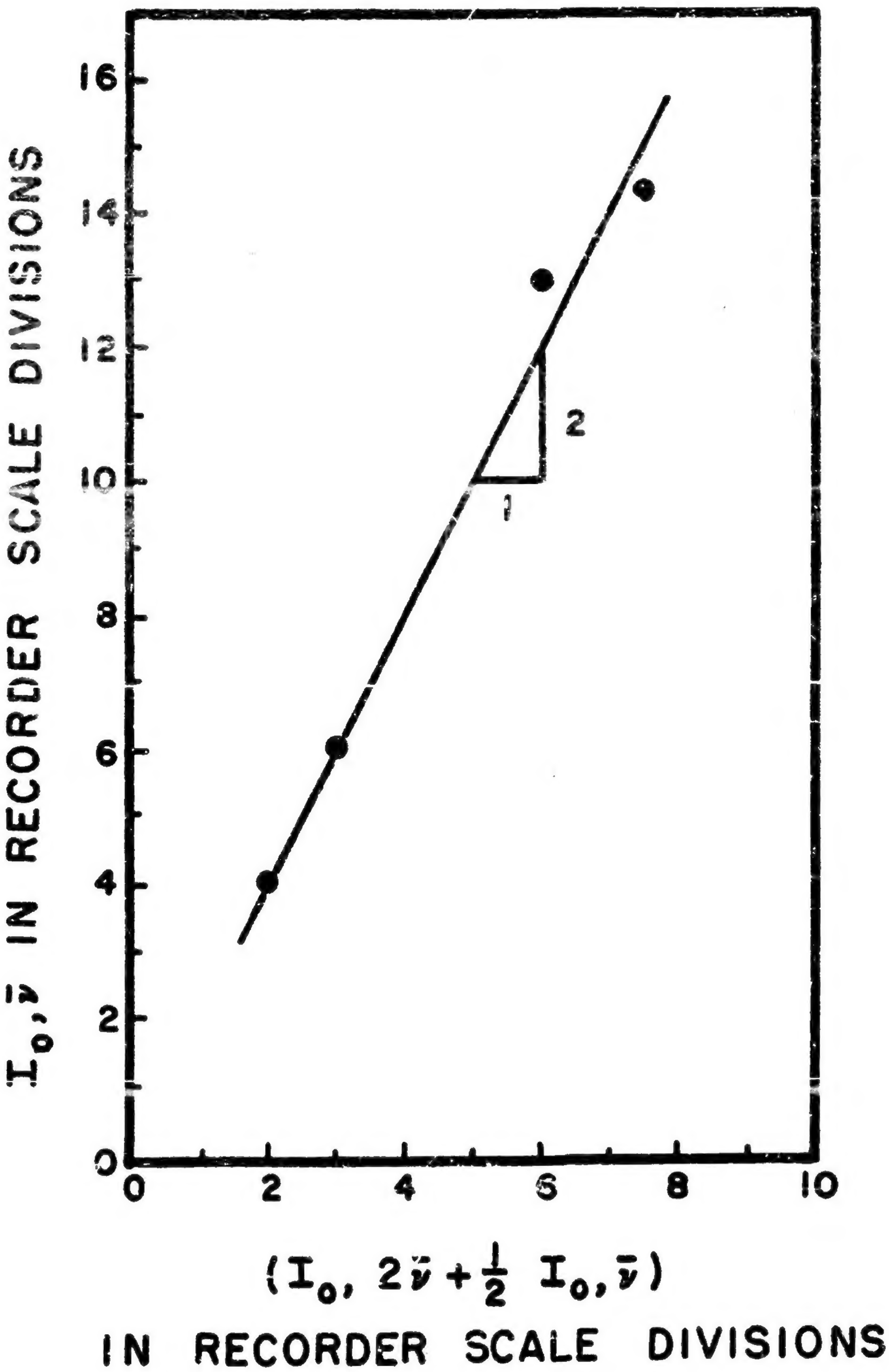
value. This allows separation of first and second order cancellation.

The separation is effected in the following manner. First, make a run over the spectral region to be examined with e = 0. Here, no wavelength cancels and the resulting spectrum serves as a reference for later ones. Then choose the values of *e* for which other runs are to be made such that there are several points at which both (on separate runs) a first order and a second order minima occur. Comparison of the first order minimum at a given wavenumber with the "e-o" spectrum will yield $I_{o,\bar{\nu}}$. A similar comparison of the second order minimum will yield $(I_{o,2\bar{\nu}} + 1/2\ I_{o,\bar{\nu}})$ since the second order of $2\bar{\nu}$ suffers complete destruction while the first order $\bar{\nu}$ is only one-half destroyed. If a plot of $I_{o,\bar{\nu}}$ vs $(I_{o,2\bar{\nu}} + 1/2\ I_{o,\bar{\nu}})$ yields a straight line of slope 2, there is negligible second order radiation. Otherwise, second order radiation exists. The plot described above -- for the region around 44 cm^{-1} -- is shown on Figure 3.

CONCLUSIONS

1) All points lie very close to the line of slope 2, and hence, it is reasonable to conclude that the 44 cm^{-1} line in the water vapor spectrum is not second order. It also might be attributed to Ozone generated by the ultraviolet of the mercury arc source, although an approximate calculation shows the Ozone line in this vicinity to be at 47 cm^{-1}.

2) It is clearly demonstrated that the lamellar grating does modulate the intensity of the incident radiation. The low ratio of signal-to-noise prevented a detailed analysis of this modulation; however, the spectra run in the 44 cm^{-1} investigation indicate that, in the minima of a given wavelength, intensity is reduced by 50 or 60% of its non-modulated value.



16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
2
1
$I_o, \bar{\nu}$ IN RECORDER SCALE DIVISIONS
$(I_o, 2\bar{\nu} + \frac{1}{2}\ I_o, \bar{\nu})$
IN RECORDER SCALE DIVISIONS

Figure 3.

BIBLIOGRAPHY

[1] T. K. McCubbin and W. M. Sinton, J. Opt. Soc. Am., 40, 537 (1950).

[2] Thomas King McCubbin, Progress Report, Contract N5-ori-166, Task Order V, July 1, 1951.

[3] William M. Sinton, Progress Report, Contract Nonr 248(01), November 15, 1952.